Fractured Zone Type Landslide and Electrical Resistivity Survey - 1 - (On the usefulness of the electrical resistivity survey at fractured zone type landslide areas)

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(On the usefulness of the electrical resistivity survey at fractured zone type landslide areas)

By Atsuo TAKEUCHI

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Abstract

The electrical resistivity survey was conducted at some fractured zone type landslide areas in order to check upon the usefullness of the electrical resistivity survey at such areas. Results provied the electrical resistivity survey very usefull at fractured zone type landslide areas.

The following information was obtained using the electrical resistivity survey;

1. An outline of the bedrock form and the existing depth of the bedrock surface at the investigated landsile area.
2. Thickness of slide layer and existing depth of slide surface.
3. Presence of underground water.
4. Supposition of an easy movement mechanism of the investigated landslide area.

1. Introduction

In discussing landslide movement mechanism and landslide preventive works, it is very important to obtain data related to the underground structure of landslide areas. Several attempts therefore, have been carried out in order to estimate the underground structure of landslide areas as exactly as possible. Most methods however, do not provide satisfactory data easily, particularly where conditions are severe.

In such conditions, Yamada[1] carried out an electrical resistivity survey at the Noudani landslide area belonging to the Tertiary type landslide in Niigata Prefecture, Momose[2] carried out the same survey at the Nishiono, Yasuyoshi and Tonomiya landslide areas belonging to the Fractured zone type landslide in Tokushima Prefecture. In every case, however, the landslide movement mechanism had been discussed on the basis of analized results of seismic prospecting which was carried out at the same time as the electrical resistivity survey. The results of the electrical resistivity survey had been given little consideration.

Consequently, landslide investigation by the electrical resistivity survey had been infrequent and little worthy of considaration. However, the survey method and the analysis method of the investigated results were improved by the ceaseless efforts of some geophysical research workers, and the survey is now being used as one of the landslide investigation methods.

Takada[3] studied the usefullness of the electrical resistivity survey at the Tertiary type landslide. He pointed out that information concerning the substant underground structure of landslide areas, landslide movement mechanism and underground water could be obtained by using the electrical resistivity survey in Tertiary type landslide areas. From these resutls, the electrical resistivity survey is being applied to many similar type landslide areas, and the investigated results offer much valuable data in regard to the landslide movement mechanism and to landslide preventive works.[4~9]

The landslide type was generally divided into three types the Tertiary type, the Fractured zone type and the Hot-spring-volcanic type, Dr. Koide.[10] Among the three types, the usefullness of the electrical resistivity survey in the Tertiary type landslide was clarified by Dr. Takada. The author therfore decided to study the applicabilitly of the electrical resistivity survey to other types of landslides, for if the electrical resistivity survey could be applied to other landslide types, valuable data could be provided for landslide movement mechanism and landslide preventive works in the same way as for the Tertiary type landslide. And on the basis of such valuable data, effective landslide investigations and preventive works could be carried out. From the results, it was considered that the expense of investigations and preventive works were considerably low.

At present time, the electrical resistivity survey is seldom conducted at landslide types other than the Tertiary type. Therefore, the author has carried out the electrical resistivity survey at the Fractured zone type landslide having many landslide aveas next to the Tertiary type, and has examined its usefullness.

2. Selected landslide area for the subject of study

In order to carry out the study, the landslide areas in Kochi Prefecture which have many typical Fractured zone type landslide areas were selected. Kochi Prefecture has 65 landslide areas which were designated as landslide preventive areas. For this, the following two landslide areas were selected as the subject of study. (Fig. 1)

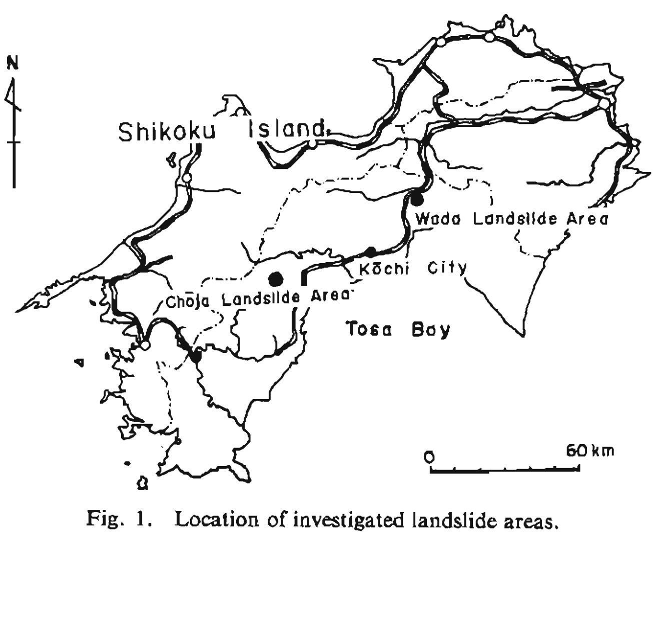


Fig. 1. Location of investigated landslide areas.

1. Choja landslide area: Takaoka-gun, Niyodo-mura Choja
2. Wada landslide area: Nagaoka-gun, Ootoyo-mura Wada

These landslide areas were selected for the under mentioned reason.

The Choja landslide area shows a flow type landslide similar to the Tertiary type among the Fractured zone type landslide. This landslide area was considered to be the most suitable landslide area in order to examine the usefullness of the electrical resistivity survey. The Wada landslide area belongs to the Mikabu green-rocks zone which has unique points among Fractured zone type landslides. This landslide was considered the best possible test in determining the applicability of the electrical resistivity survey.

3. Study method

On the hypothesis that the electrical resistivity survey used at Tertiary type landslide areas could be applied equally at the Fractured zone types, the electrical resistivity survey was carried out at the selected landslide areas in advance of other landslide investigations. On the basis of the results obtained other landslide investigations were carried out. The author compared the results with those of the landslide investigations carried out after the electrical resistivity survey.

4. Results and discussion

4—1 *Application at the Choja landslide area*

4—1—1 Outline of the Choja landslide area.

The Choja landslide area is located at Niyodo-mura, Takaoka-gun, Kochi Prefecture. From the topography, the boundary between non-movement soil mass and movement soil mass is very distinct. The moving area at present is about 1,000 meters long by 100—300 meters wide, and its area is about 14.3 ha.. The difference in elevation from the top part to the tip of this landslide area is 230 meters and the head scrap reachs the pass. From the geology, the landslide area belongs to the Kurosegawa tectonic zone in the Chichibu terrain, and is a landslide of the serpentine boundary layer which is found between the clay slate of Palaeozoic. This landslide area is typical for Japan.[11] There are partial Mitaki igneous rocks which are the lenticular intrusive rock of the Kurosegawa tectonic zone. This landslide body consisted of the following material from the upper layer to the lower: debris (upper-weathering material of serpentine, lower-weathering material of clay slate)—upper layer clay slate—serpentine or schalstein—lower layer clay slate—sand-stone.

On the utilization of land, the upper part and either side are utilized a copse, the other part being utilized as inclinated fields.

The active condition of the area, allording to village history,[12] is of a landslide occuring on a large scale around 790 A.D., and periodically after that, in large scale movements. From these movements, the Choja river bed was upheaved, and movement soil mass was pushed to the other side of the Choja river. This soil mass can still be seen at the other side of the landslide area at the present time. It can be shown from topographical maps that the Choja river has been intercepted and has conged course during large scale landslide movements. At the time of the large scale movement in 1885, the Choja river changed to the course it keeps today. The speed of this landslide soil mass is about one meter per year, and this condition has been continuing for 70 years. Therefore, on till preventive works are carried out in earnest, the road crossing in this area will continue to be destroyed near the boundary of landslide movement at frequent intervals, and fields pushed out to the Choja river, during flood. The field mass and much farm produce has been washed away, giving considerable damage to people in the area.

In order to obtain referent data for landslide preventive works in such conditions, landslide investigations have been conducted by Kochi University and Kyoto University. Consequently, the electrical resistivity survey was carried out parallel with the seismic prospecting survey and the natural radio prospecting survey in order to examine the usefullness of the electrical resistivity survey in such landslide areas. Carring out the following landslide investigations on the basis of the results of the above mentioned investigations, synthesizing the results of the following landslide investigations, and determining the usefullness of the electrical resistivity survey were made.

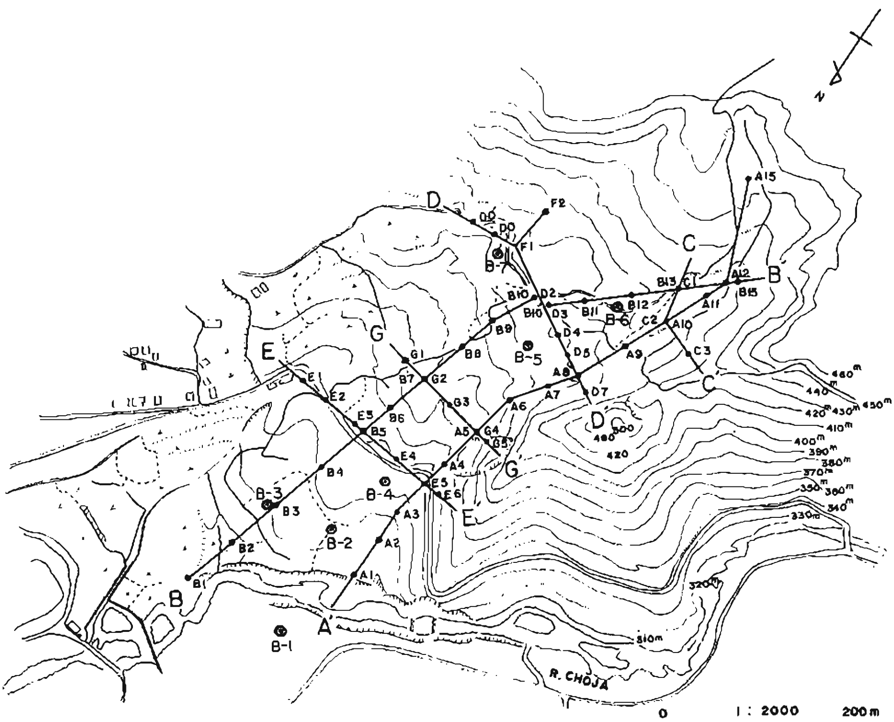


Fig. 2. Topographical map of the Choja landslide area (including the location of the measuring points of the electrical resistivity survey).

4–1–2 Investigation extent and methods.

The electrical resistivity survey was carried out at 44 measuring points which are indicated in Fig. 2. The disposition method of the electrodes were used as in Wenner's four electrodes method, and the measuring depth was 30 meters max.. The measuring line of each measuring point was roped off as ineffective to the topography as far as possible. The instrument used was the "Specific Earth Resistance Tester (Type L–10)" (manufactured by Yokokawa Electric Works). The measured results were represented on ρa-a curves, and these curves were analyzed by the Shlumberger's standard curves. Using these results, the underground structure of the landslide area was assumed and the distributed condition of the apparent resistivity values in the area was examined by the analyzed results of the horizontal electric profiling.

4–1–3 Assumed results of the underground structure.

Measuring lines were prepared in the landslide area making a cross section of the measuring lines. To determine the underground structure, the results of the electrical resistivity survey were entered into the cross section. (Fig. 3a and b)

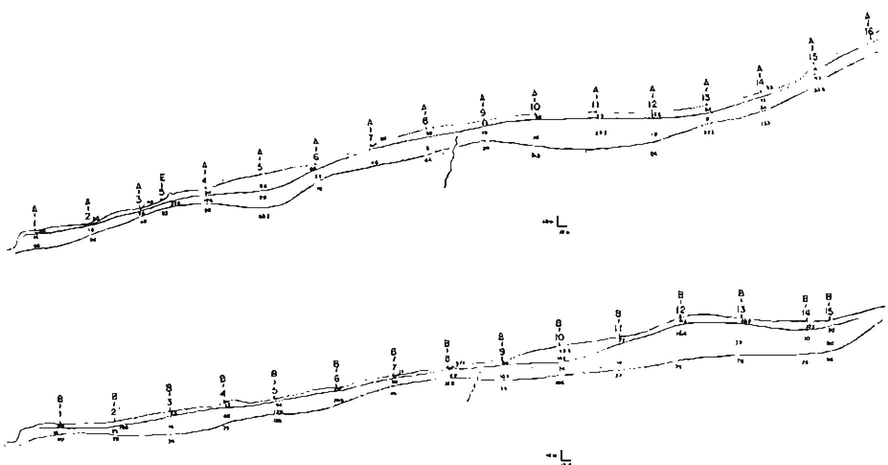


Fig. 3(a, b). Assumed diagrams of the underground structure by the electrical resistivity survey (unit of numbers = kΩ-cm).

A–line: This line runs through the east side of the area. Under this section, the underground structure of the cross section constitutes approx three layer of resistivity. The first layer shows 18–98 kΩ–cm in resistivity values, and the thickness of this layer is 2–13 meters. The second layer shows 8–46 kΩ–cm in resistivity values, and the thiskness of this layer is 5–25 meters. The third layer shows 24–153 kΩ–cm in resistivity values, and the depth from surface to the third layer is 7–30 meters. A belt of discontinuity exists between A–8 and A–9, and it is probable that landslide soil mass in this section can be divided into two blocks.

B–line: This line runs through the west side in the landslide area. The underground structure of this cross section constitutes approx three layers as in the A–line in resistivity. The first layer shows 2.3–148 kΩ–cm in resistivity values, and the thickness of this layer is 2–15 meters. The second layer shows 0.5–36 kΩ–cm in resistivity values, and the thickness of this layer is 3–30 meters. The third layer shows 20–180 kΩ–cm in resistivity values, and the depth from surface to the third layer is 5–37 meters. The belt of discontinuity exists between B–8 and B–9 as in the A–line, and it is probable that the landslide soil mass in this section can be divided into two blocks.

4–1–4 Results of the horizontal electric profiling.

The horizontal electric profiling which was used at the Tertiary type landslide area in order to determine the condition of the underground water was carried out at this landslide area.

Fig. 4a–e shows the distributed condition of the apparent resistivity values at each electrode span (a = 2, 5, 10, 20 and 30 meters).

a = 2 meters: The distributed area of the low apparent resistivity values less than 20 kΩ–cm are at the upper and lower parts in the east of the landslide area.

a = 5 meters: The distributed areas of the low apparent resistivity values are to the north of the cross road and at the upper part of the east of the area.

a = 10 meters: The distributed areas of the low apparent resistivity values are in

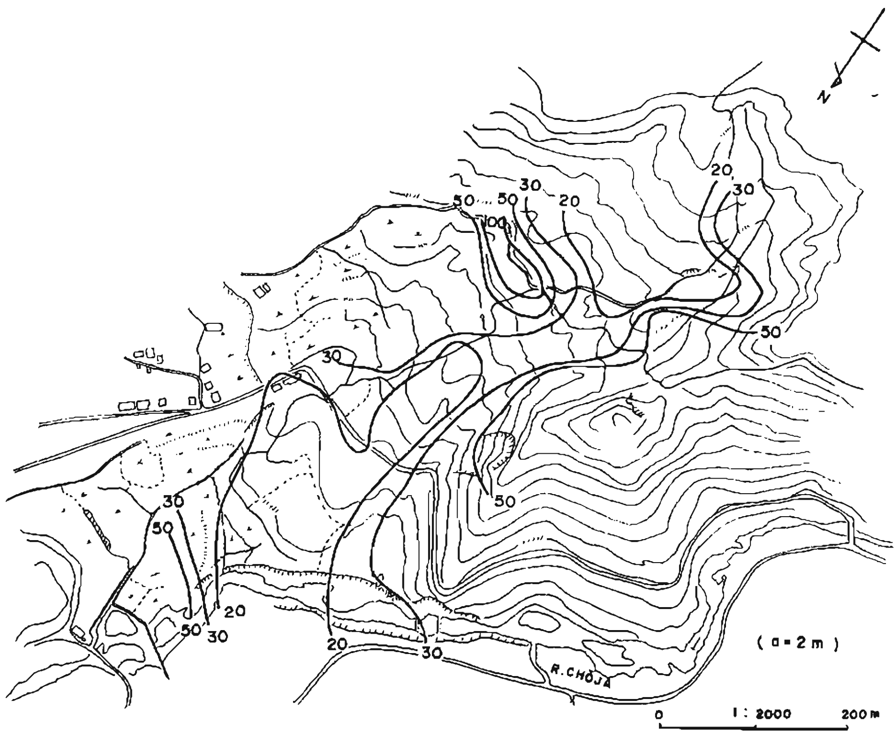


Fig. 4(a). Distributed diagram of the apparent resistivity values. (a = 2m) (unit of numbers = kΩ-cm)

Fig. 4(b). Distrituted diagram of the apparent resistivity values. (a = 5 m) (unit of numbers = kΩ-cm)

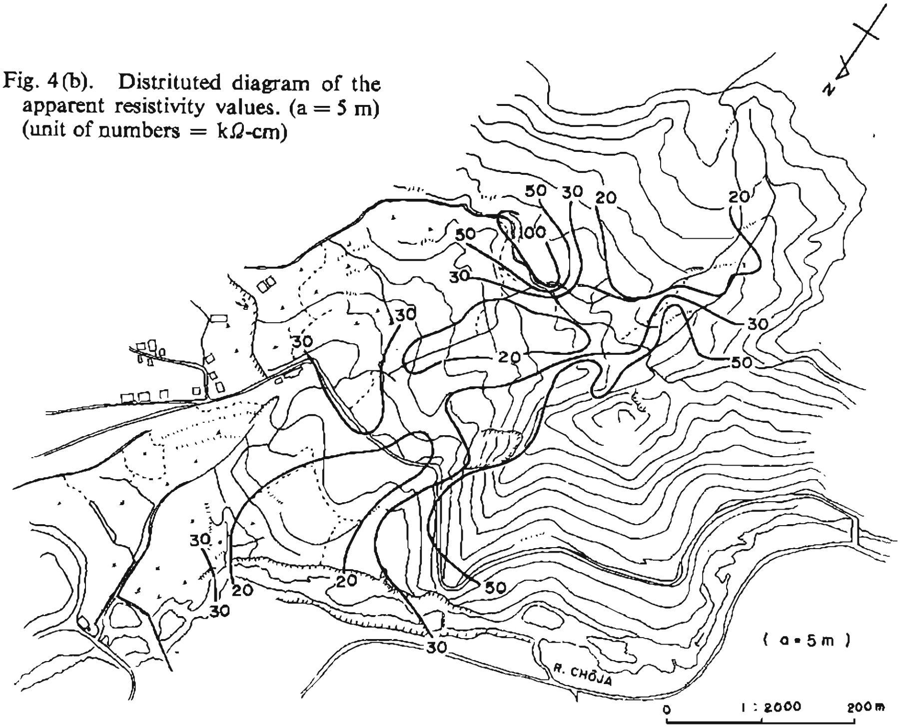


Fig. 4(c). Distributed diagram of the apparent resistivity values. (a = 10 m) (unit of numbers = kΩ-cm)

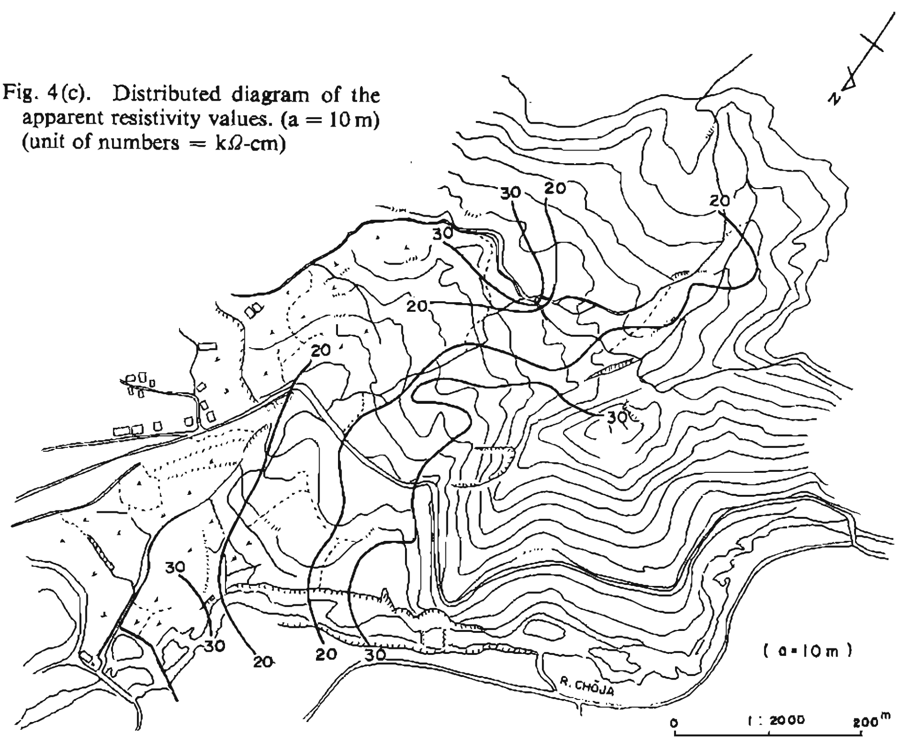


Fig. 4(d). Distributed diagram of th apparent resistivity values. (a = 20 m) (unit of numbers = kΩ-cm)

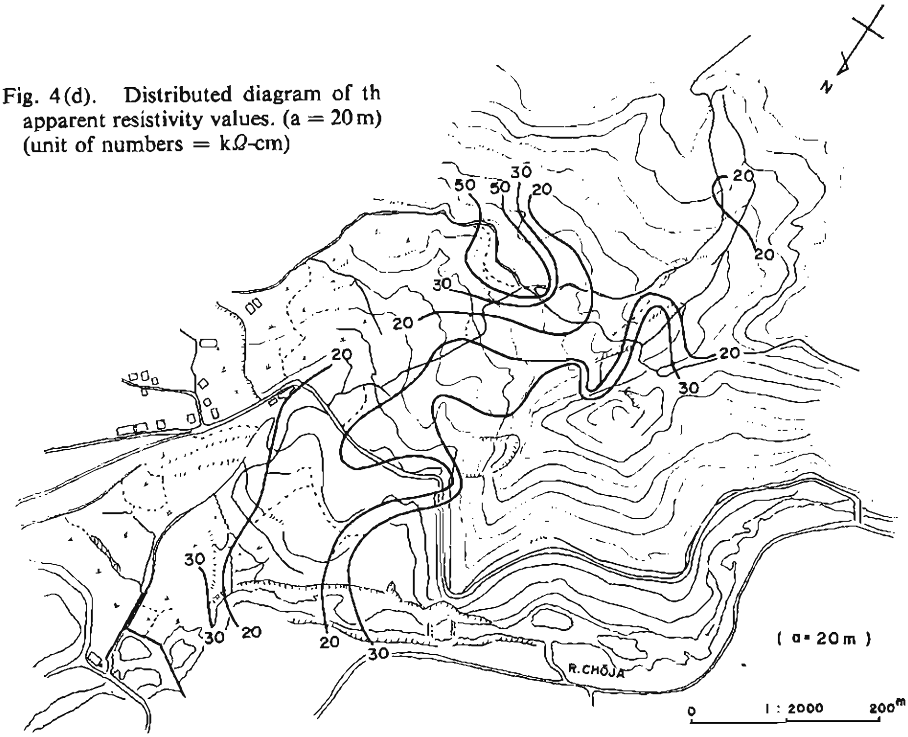
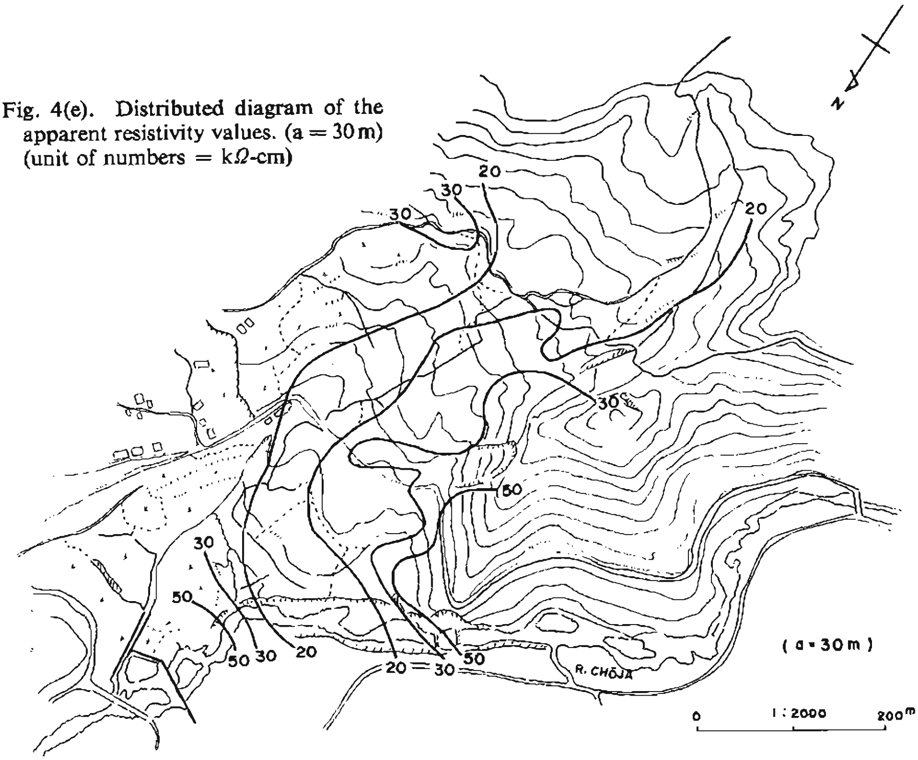


Fig. 4(e). Distributed diagram of the apparent resistivity values. (a = 30 m) (unit of numbers = kΩ-cm)



two or three places at a = 2 and 5 meters, but at this electrode span, the area stretches one zonal, and is in the east of the area.

a = 20 meters: Equal to the case of a = 10 meters approx.

a = 30 meters: Equal to the case of a = 10 and 20 meters approx.

Fig. 5 shows the distributed areas of the low apparent resistivity values less than 20 kΩ–cm which were obtained at each electrode span. With this figure, it is shown that the distributed areas of the low apparent resistivity values exist in two places, the upper part in the east of the area and from the central part to the Choja river in the east at all electrode spans, the distributed area of the low apparent resistivity values exists in the east part of the area at the electrode span a = 10–30 meters.

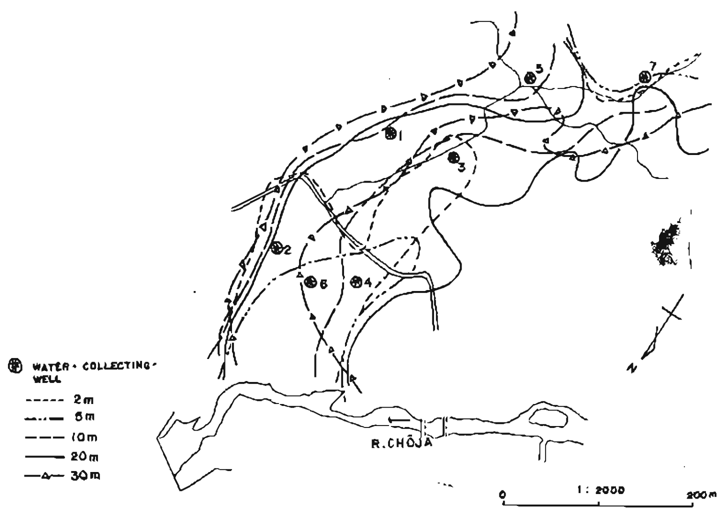


Fig. 5. Distributed diagram of the low apparent resistivity values less than 20 kΩ-cm on 4th Aug. 1964.

4–1–5 Summary of the results of the electrical resistivity survey.

The underground structure of the landslide area consists of nearly three structural layers shown on the basis of results from electrical resistivity survey. The average resistivity values for each layer is as follows; the first layer = 67.6 kΩ–cm, the second layer = 16.0 kΩ–cm and the third layer = 63.7 kΩ–cm. The assumed layers which produced the landslide movement were the second and the first layers, and the resistivity values of these layers show 0.5–46.0 kΩ–cm. Examining the cross sections at A and B lines, it is believed that the landslide soil mass can be divided the two blocks at A–8 and A–9, and B–8 and B–9. Observing the present topography, the protuberance of the soil mass exists at these measuring points and vicinity.

On the analyzed results of the horizontal electric profiling, the distrinuted areas of low apparent resistivity values less than 20 kΩ–cm are mainly at the upper and lower parts in the east of the area without distinction of the larger and smaller electrode spans.

When the results of the electrical resistivity survey at the Tertiary type landslide areas are interpreted and adapted to the Fractured zone type, results are as follows: The underground structure of this landslide area probably consists of three layers. It is highly probable that the second layer is the slide layer because it shows a lower resistivity values than the other layers. If it is assumed that the third layer is bedrock, evident from the form of the layer's surface, it is also reasonable to assume that this landslide area is divided into two blocks which are the upper and the lower parts at the vicinity of the measuring points 8 and 9 of both measuring lines and that the upper soil mass produces the rotation type slide and the lower soil mass produces the flowing type slide.

On the other hand, when examing the diagram of the distributed condition of the low apparent resistivity values, the distributed areas of the low apparent resistivity values are at the upper and the lower parts in the east of the landslide area. It seems that these distributed areas belong to one of the following; an existing area of abundant underground water having a bad effect on the landslide soil mass, a weathered area of landslide soil mass other than the landslide soil mass, or an area of unstable soil mass which might move in future. At present, it is assumed that the distributed areas of the low apparent resistivity values in this landslide area belong to the existing area of abundant underground water because these areas are more active than the other parts of the area and have numerous gush points of underground water.

4-1-6 The results of the landslide investigations on the basis of the results of the electrical resistivity survey.

In order to confirm the usefullness of the results of the electrical resistivity survey, nine borings were carried out in the landslide area. The underground structure obtained from the electrical resistivity survey was compared with the results of boring, and the belt of discontinuity discovered by the electrical resistivity survey investigated. The depth of the slide surface and the bedrock were confirmed by internal strain meters inserted into the bore holes. Investigations of the underground water utilized the bore holes and the meaning of the distributed areas of the low apparent resistivity values obtained by the electrical resistivity survey were examined.

Fig. 6 (a and b) includeds the boring profile in the underground structure cross section assumed by the electrical resistivity survey. Table 1 shows the mutual difference of the depth of slide surface and bedrock which were required from Fig. 6. With this table, the difference between the depth of bedrock assumed by electrical resistivity survey and the depth of bedrock which was confirmed by the boring profile was approx $+4 \sim -4$ meters. On the other hand, the difference between the depth of the slide surface assumed by electrical resistivity survey and the depth of the slide surface confirmed by the internal strain meters was $+1.7 \sim -2.5$ meters. Finally, in assuming the underground structure using the electrical resistivity survey, it was clarified that results could sufficiently describe the actual form of the bedrock and the slide surface at the investigated area. It was observed that the slide layer assumed

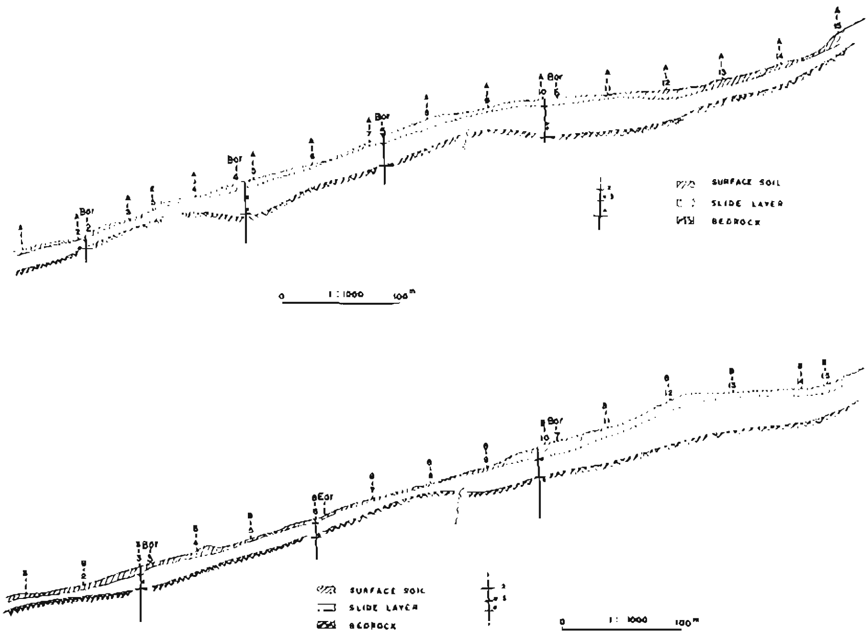


Fig. 6(a,b). Assumed diagrams of the underground structure.
1. position of bore hole, 2. boundary of each layers, 3. slide surface observed by internal strain meters

by the electrical resistivity survey was including some slide surface and indicating that if such a method thus shows the slide layer it might also be applied to the Fractured zone type landslide as it is applied to the Tertiary type.

Comparing the boring profile and the underground structure diagram produced by the electrical resistivity survey, it was shown that the first layer on the electrical resistivity survey was a clay mixture of gravel of serpentine and clay slate on the boring profile, and that the second layer was a weathered material of serpentine and clay slate. It was confirmed that the third layer, assumed to be bedrock from the electrical resistivity survey, was a comparably hard rock of clay slate on the boring profile.

Table 1. Difference between assumed and confirmed depth.

Number of bore hole	B - 2	B - 3	B - 4	B - 5	B - 6	B - 7
Difference of A from B	+1.7	−2.5	+4.0	−2.0	−4.0	+0.5
Difference of C from D	+1.7	−1.0	0.0	0.0	−4.0	−2.0

(units of number = meters)

A: assumed depth of bedrock by the electrical resistivity survey.
B: confirmed depth of bedrock by boring.
C: assumed depth of slide surface by the electrical resistivity survey.
D: confirmed depth of slide surface by the internal strain meters.

The existance of the discontinuity belt was assumed between the measuring points 8 and 9 in A and B of both measuring lines. This discontinuity belt was the abnormal zone which was recognized by the results of the seismic prospecting and also by the natural radio prospecting surveys. It was therefore considered that the very strongly fractured rocks existed in this belt and vicinity. Borings were then carried out and from the results it was recognized that the belt consisted of a very strongly fractured rock.

In order to investigate the meaning of the distributed area of low apparent resistivity values utilizing bore holes, different kinds of underground water investigations were conducted in the area. From the results it was assumed that there existed abundant underground water in the east of the landslide area. As the distributed areas of the low apparent resistivity values approximately agreed with the above mentioned area, it was assumed that the distributed areas of the low apparent resistivity values were the existing area of abundant underground water.

It was considered that for water to collect in such abundance, the weathering of the landslide soil must have been accelerated and the landslide movement activated. Such a consideration was supported by observation of the earth surface movement. In order to prevent this movement, it is necessary that exstensive underground draining of the area be made. Seven underground water collecting wells were therefore constructed in and around the area of low apparent resistivity values by the prefecture authorities. As a result the water (total 260 *l*/min.) was collected at the underground wells No. 1, 2, 5, 6 and 7 as in Fig. 5. (1965) These underground water collecting wells were constructed in the distributed areas of the low apparent resistivity values. On the other hand, wells No. 4 and 3 which were constructed outside the distributed areas of the low apparent resistivity values collected very little (total 20 *l*/min.). (1965) It is not unreasonable to assume therefore, that the distributed areas of low apparent resistivity values were the existing areas of abundant underground water.

4–1–7 Determination of the effectiveness of underground water drainage works using the electrical resistivity survey.

Underground water collecting wells were constructed in this landslide area, resulting in a large quantity of the underground water being drained. There was no opportunity however, to examine the extent of drainage effectiveness and four years have since glided away.

The opportunity to carry out an electrical resistivity survey in the Choja landslide presented itself again in July, 1969 and the author therefore conducted further tests on the effectiveness of underground water drainage.

It had been confirmed that the electrical resistivity survey was an effective method in determining the effectiveness of underground water drainage at the Kushibayashi landslide area in Shiga Prefecture.[13] In order to examine whether this method could or could not be applied to the Fractured zone type landslide area, the electrical resistivity survey was carried out at approximately the same measuring points as those four years ago. The results are shown in Fig. 7. Comparing these results with

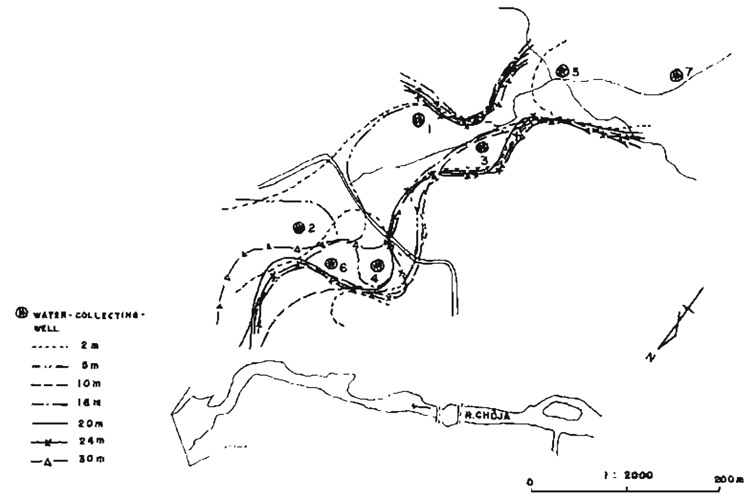


Fig. 7. Distributed diagram of low apparent resistivity values less than 20 kΩ-cm on 26th July 1969.

the previdus ones (Fig. 5), the following facts were clarified. The distributed areas of low apparent resistivity values existing at the tips of each electrode span at the previous landslide, moved to the east tip of the second landslide electrode spans. At the central part of the second landslide area, the distribution of low apparent resistivity values had been extending without coordination at each electrode span of the previous landslide, but at the second, these areas existed concentrically at the east part of each electrode span. The cause being conjectured as follows.

The distributed areas of the low apparent resistivity value at the center of the area was due to the underground water which, previously had flowed freely, being collected at the underground water collecting wells, the area and neighbourhood without wells decreased in underground water and the water content of the landslide soil mass droped, the apparent resistivity values rising at that rate. As a result, it is thought that the distributed area of the low apparent resistivity values moved to the east part of the landslide area were wells had been constructed. However, in regard to the distributed areas of low apparent resistivity values at the tip of the area, the water which had been filtering from the upper part of the landslide area leaded to the tip and water was proceeding or accelerating with the landslide movement. As the underground water collecting wells had been constructed in the area after this, the greater part of the water had been drained and the underground water had not quite reached the tip of the area. For this reason the water content of the landslide soil mass at the tip of the landslide area and the neighbourhood without underground water collecting wells dropped, and the apparent resistivity values rised accordingly. From these results, it is thought that the distributed area of low apparent resistivity values disappeared from the tip of the landslide area.

In the east part where the wells had been constructed, the underground water had collected very effectively and was drained sufficiently by natural methods. It has since been confirmed by observing the ground surface movement that the landslide have been decreasing. This fact indicates the effectiveness of the underground water collecting wells.

4–2 *Application at the Wada landslide area*

4–2–1 Outline of the Wada landslide area.

The Wada landslide area is located at Ootoyo-mura, Nagaoka-gun, Kochi Prefecture. This landslide area belongs to the North shore of the Mikabu greenrocks zone. As generally seen at such landslide areas, rice field are situated on the high land 730 meters above the sea level. Topographically, the tip of the landslide area is at 490 meters, and there is a flow type slide between 545 meters and 490 meters. There is a compression zone between 580 meters and 545 meters and a gentle slope between 590 meters and 580 meters, this slope being utilized as large rice fields. There is a steep slope between 620 meters and 590 meters utilized as 'semmaida' (numerous group of small rice fields). In the neighbourhood there is a top part to the landslide area. Above this, there is a large flat face between 660 meters and 630 meters, and 730 meters and 700 meters. These flat faces are utilized as rice fields. There is a spring point at 730 meters having good quantity water. Below this area many spring points can be seen. (Fig. 8)

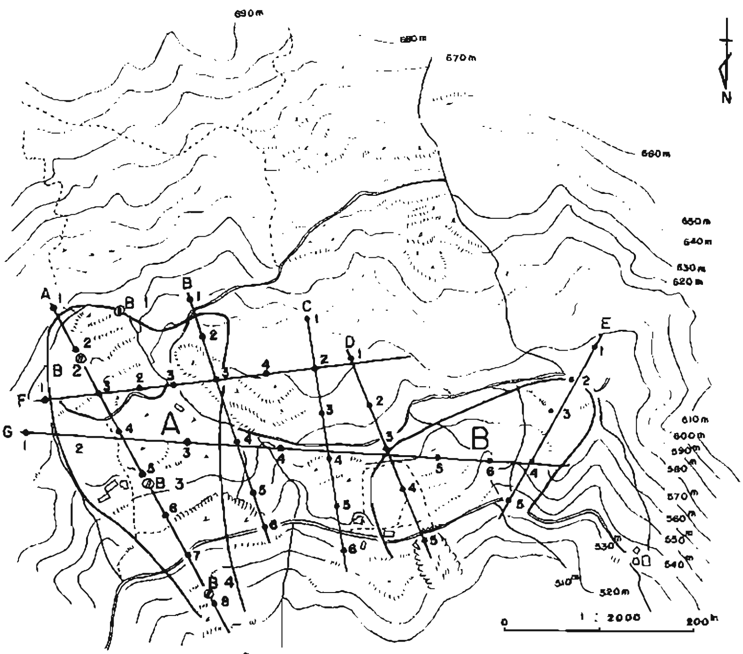


Fig. 8. Topographical map of the Wada landslide area (including the location of the measuring points of the electrical resistivity survey).

4–2–2 Investigated extent and methods.

An electrical resistivity survey was carried out at A and B blocks in the Wada landslide area. (Fig. 8) Measuring points were 41. The disposition of the electrode was as in Wenner's four electrode method, and the measuring depth was 50 meters max.. The measuring line of each measuring point was roped off as ineffective to the topography far as possible. The instrument employed was the "Specific Earth Resistance Tester (Type L–10)" (manufactured by Yokokawa Electric Works). Results were represented on ρa–a curves, and these curves were analyzed by the Schlumberger's standard curves. Using these results the underground structure of the landslide area was assumed at each cross section, and the distributed condition of the apparent resistivity values in the landslide area was examined by the analyzed results of the horizontal electric profiling.

4–2–3 Assumed results of the underground structure.

In order to determine the underground structure, the results of the electrical resistivity survey were entered into each cross section. Here, the cross section of A line is the subject of discussion. (Fig. 9)

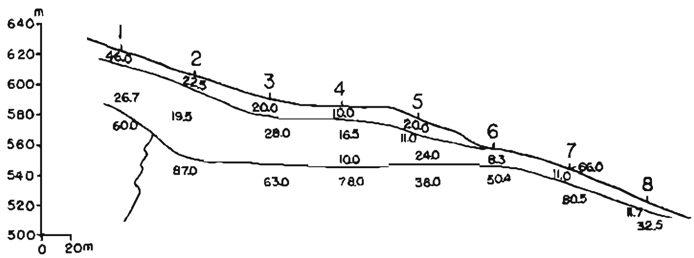


Fig. 9. Assumed diagram of the underground structure by the electrical resistivity survey (unit of numbers = kΩ-cm).

This line runs through the center of A block in the Wada landslide area. As shown in Fig. 9, the underground structure of the cross section indicats a structure of approximately three layers. The first layer shows 10–46 kΩ–cm in resistivity values. The second layer shows 8.3–28 kΩ–cm in resistivity values. And the third layer is separated into two blocks, one of which constitutes the measuring point of A–1, the other constituting the measuring points A–2$\sim$A–8. The former block shows 600 kΩ–cm in resistivity values, and the later 32.5–80.5 kΩcm. It is though that each measuring point has a different character in resistivity to the third layer. The assumed layers which occurred in landslide movement are the first and second layers, and the thickness of these slide layers has a maximum depth of 58 meters at measuring point A–2, and 10 meters at measuring point A–7. The part of the low resistivity values at measuring point A–6 and neighbourhood shows the flowing type slide, and the resistivity values are lower than the other measuring points.

The underground structure of A block of this landslide area constitutes nearly three layers on the basis of the results of the electrical resistivity survey. The resistivity values of each layer are as follows: the first layer = 6–84 kΩ–cm, the second layer = 8–44 kΩ–cm and the third layer = 32–80 kΩ–cm and 108 kΩ–cm or more.

4–2–4 Results of the horizontal electric profiling.

Horizontal electric profiling was carried out at this landslide area. Fig. 10 (a–h) shows the distributed condition of the apparent resistivity values at each electrode span (a = 2, 5, 10, 16, 20, 30, 42, and 50 meters).

a = 2 meters: The distributed areas of the low apparent resistivity values less than 20 kΩ–cm are at all areas of A block and the measuring point C–5 and its neighbourhood and E–line and its neighbourhood.

a = 5 meters: Equal to the case of a = 2 meters approx.

a = 10 meters: The distributed area of the low apparent resistivity values extends throughout A and B blocks.

a = 16 meters: The distributed area of the low apparent resistivity values decreased a little, especially the distributed area of the high apparent resistivity values appeared in the south of A block.

a = 20 meters: Equal to the case of a = 16 meters approx.

a = 30 meters: The distributed areas of the low apparent resistivity values are at the center of A block and the east and west end of B block.

a = 42 meters: The distributed areas of the low apparent resistivity values are at the measuring points of B–5, C–3 and D–4 like connecting A and B blocks. The other distributed area is in the south of A block.

a = 50 meters: Equal to the case of a = 42 meters approx.

Fig. 11 shows the distributed areas of low apparent resistivity values less than 20 kΩ–cm which were obtained at each electrode span. This figure indicates that the distributed areas of the low apparent resistivity values are in three steps to the dimension of electrode span (a). In the case of a = 2–10 meters, the distributed area of low apparent resistivity values is in all areas of A and B blocks. In the case of a = 16–30 meters, the distributed areas are at the weak parts of the landslide soil mass at A and B blocks, and in the case of a = 42–50 meters, the distributed areas are in the neighbourhood of the connecting area of A and B blocks and in the south of A block.

4–2–5 Summary of the results of the electrical resistivity survey.

The hypothesis applied at the Choja landslide area was introduced at the Wada landslide area, and the results of the electrical resistivity survey were examined.

Concerning the underground structure, the third layer was assumed to be bedrock, the form of the surface is shown in Fig. 12. The distributed areas of the low apparent resistivity values less than 20 kΩ–cm belong to one of the following areas: the area of abundant underground water with bad effects on the landslide soil mass, the weathered area of the landslide soil mass other than the landslide soil mass itself, and an unstable area which will probably move in future. At present, it is unsure which distributed areas of low apparent resistivity values belong to which area. This must awaite the results of future landslide investigations. But considering the con-

Fig. 10. (a-h), Distributed diagrams of the apparent resistivity values (a = 2, 5, 10, 16, 20, 30, 42 and 50 meters). (unit of numbers = kΩ-cm)

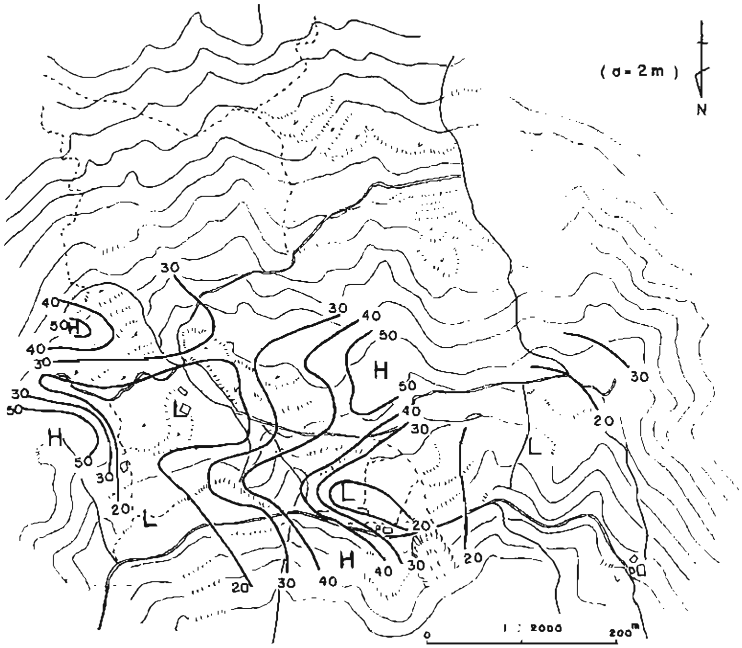


Fig. 10 (a)

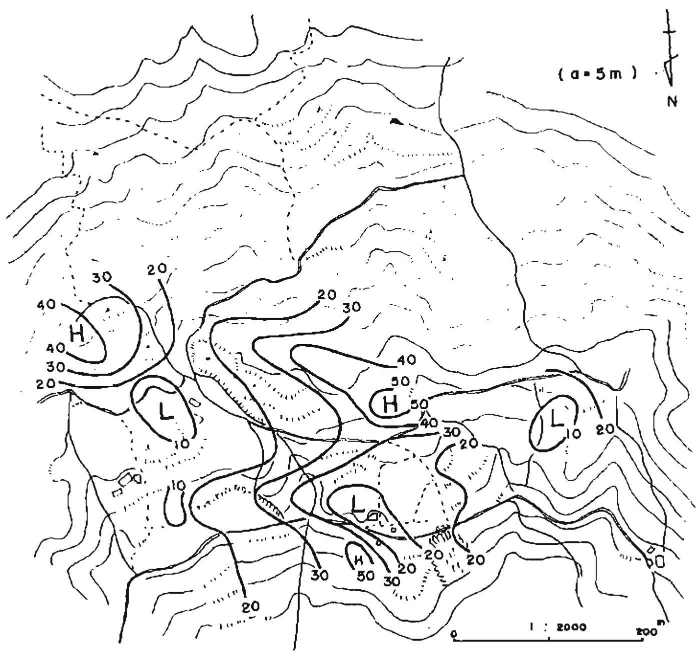


Fig. 10 (b)

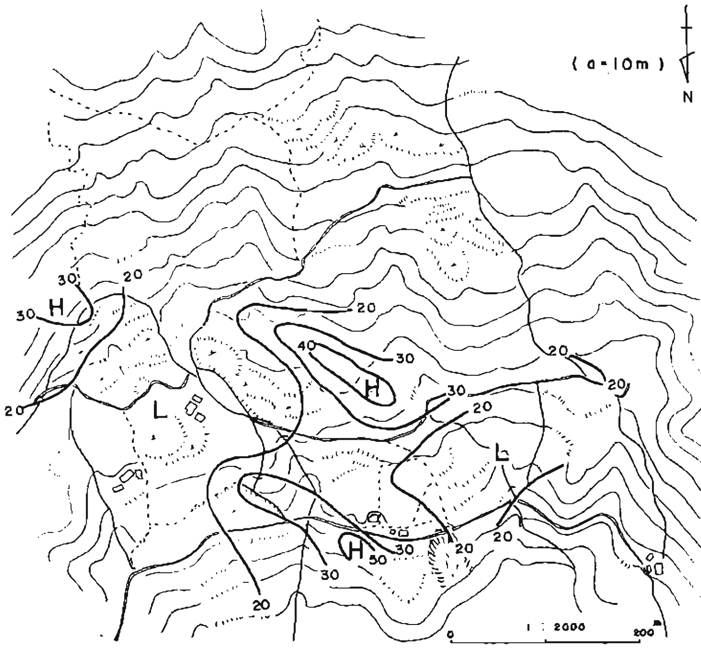


Fig. 10 (c)

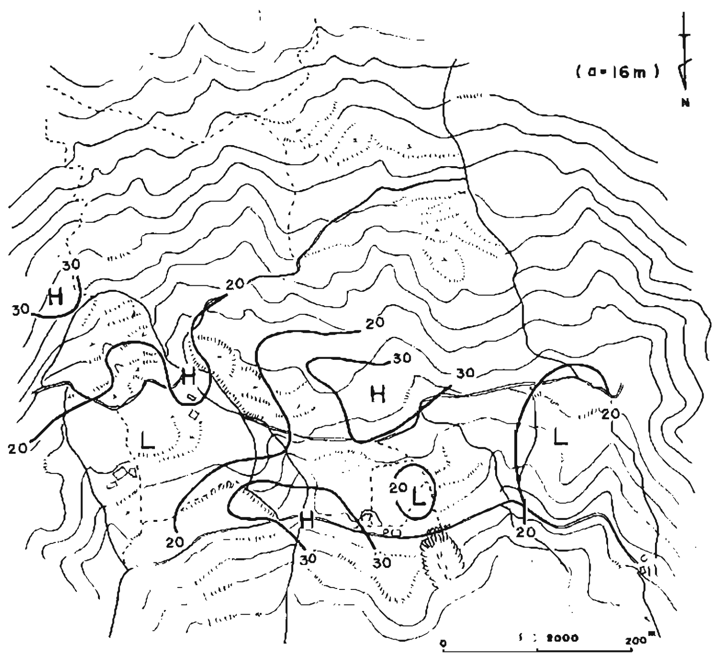


Fig. 10 (d)

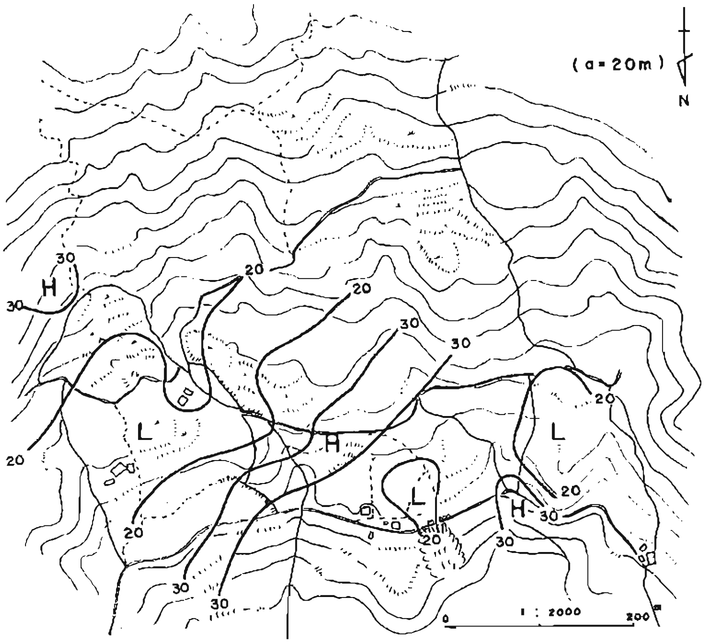


Fig. 10 (e)

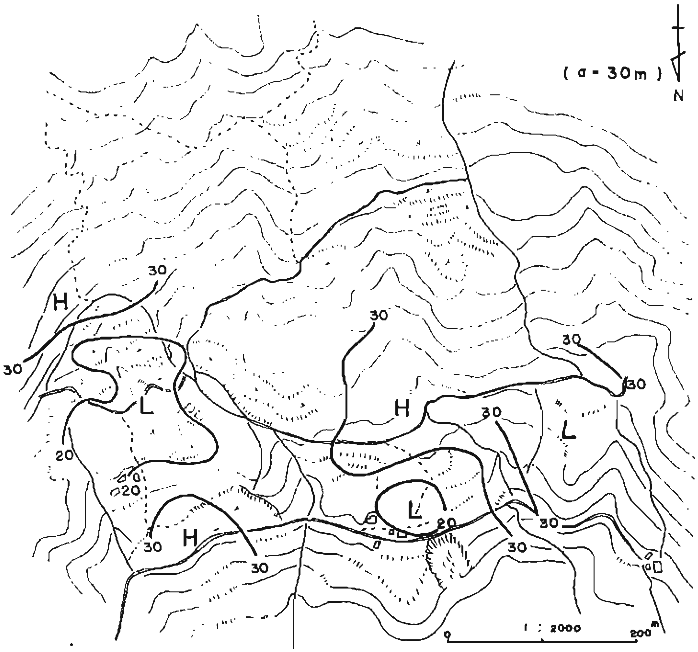


Fig. 10 (f)

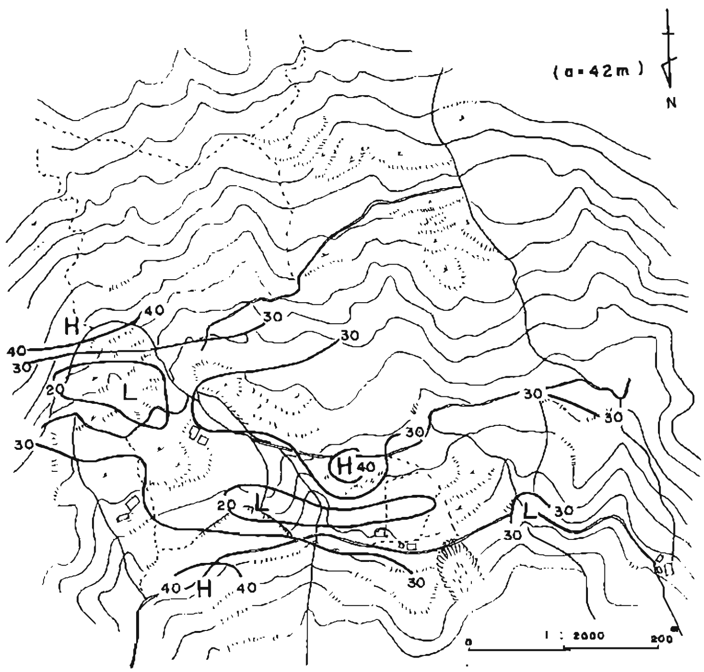


Fig. 10 (g)

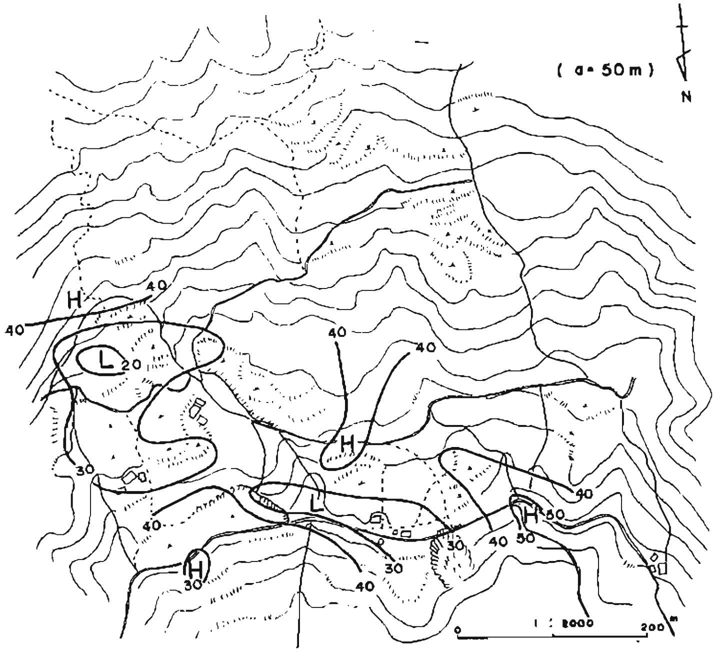


Fig. 10 (h)

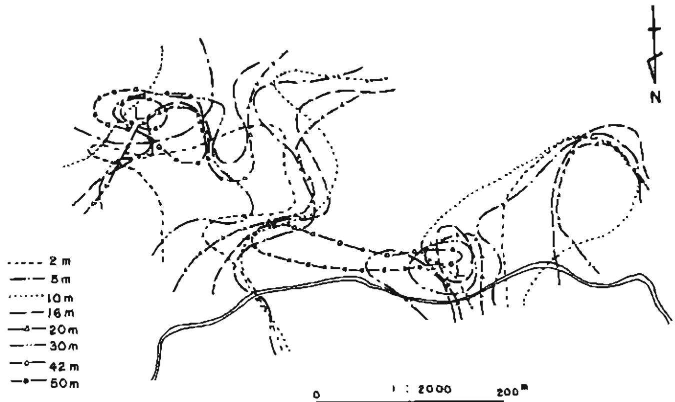


Fig. 11. Distributed diagram of the low apparent resistivity values less than 20 kΩ-cm.

dition of the field, the distributed areas of low apparent resistivity values in the area agree with the active movement area. Accordingly, the distributed areas in the area may possibly belong to the existing area of the abundant underground water having had effects on the landslide soil mass or the weathered area of the landslide soil mass other than the landslide soil mass itself.

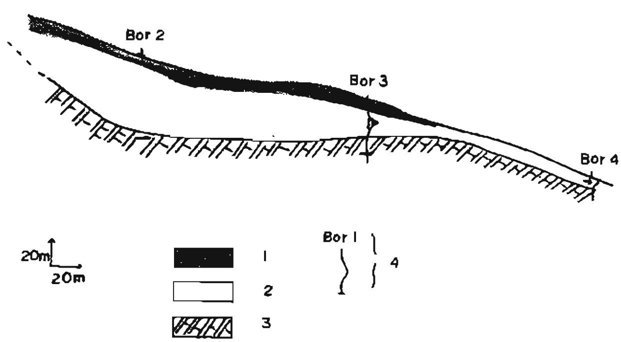


Fig. 12. Assumed diagram of the underground structure.
1. surface soil layer, 2. slide layer, 3. bedrock layer, 4. assumed forms of the internal strain meter pipes.

4–2–6 Results of the landslide investigations on the basis of results of the electrical resistivity survey.

From the results of the electrical resistivity survey conducted on the underground structure, it is indicated that A block of this landslide area consists of two parts, one of which is the rotation type slide which has a maximum depth at measuring point A–2 and neighbourhood, the other is the flowing type slide below the measuring points A–6. In order to confirm the depth of the bedrock and to investigate the movement conditions of the landslide soil mass, three bore holes were made in the neighbourhood of the measuring points A–2, A–5 and A–8 in A block. From these results it was clarified that the landslide soil mass which was probed by the electrical resistivity method was weathered material and gravels of the Mikabu green-rocks, and the bedrock was a non-weathering rock of schalstein. A sharp difference existed between the weathered material of the green-rocks and the bedrock of schalstein. It was thought therefore, that the debris which constituted the green-rocks accumulated on the bedrock in the past, the debris weathering and producing the present landslide movements.

From the results of the internal strain meters which were inserted into the bore holes, it was indicated that B–2 is producing the thick layer slide, B–3 is producing the protruding phenomena between 13 meters and 21 meters depth, and B–4 is producing the flowing type slide at parts shallower than 9–11 meters. (Fig. 12)

4–2–7 Apparent movement mechanism and preventive works.

The electrical resistivity survey was conducted before other landslide investigations in the Wada landslide area, and on the basis of the results the underground water investigation, slide surface investigation etc., were carried out. Synthesizing these results, the movement mechanism of A block was determined and the usefullness of the electrical resistivity survey examined.

From the results of the electrical resistivity survey, A block constitutes two movement soil masses which have a different movement mechanism at each soil mass. The upper soil mass has an apparent slide surface at 30–50 meters which is weak to a considerable depth. The lower soil mass has an apparent slide surface at 5–8 meters depth and the soil mass, which inclues a large quantity of water, indicates a fluid condition. On the other hand, from the results of the internal strain meters, it is indicated that a flowing type slide exists at a shallow part less than 10 meters deep. It was also observed that the middle soil mass was producing the protruding phenomena between a depth of 13 meters and 21 meters. The depth of each slide surface agreed approximately with the depth of the slide surface assumed by the electrical resistivity survey.

From the results of the underground water at A block, the spring points were mainly at the measuring points A–6 and A–7 and neighbourhood. At the village road and neighbourhood, the soil mass was especially weakened by the underground water and the breaking of the soil mass can always be seen. At the measuring point A–8 and neighbourhood, the soil mass was weakened by the underground water and the soil mass is in a free state of flow. It has been assumed from the results of the underground water investigations that the underground water which is having a bad effect on the landslide movement is the shallow layer of underground water in the landslide area.

Summarizing the above results, the landslide movement mechanism of A block is assumed to be as follows: (Fig. 13)

Water supplied in large quantities like that of heavy rain, permeates into the landslide soil mass immediately. The water flows down into the soil mass and gushs

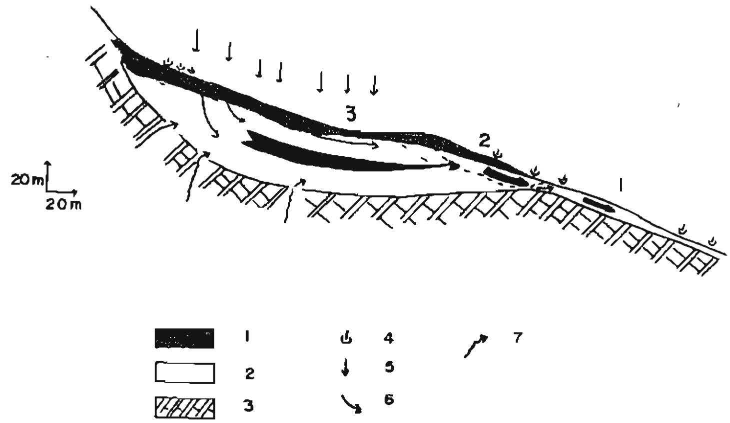


Fig. 13. Assumed movement mechanism diagram of the Wada landslide area.
1. surface soil layer, 2. slide layer, 3. bedrock layer, 4. spring points, 5. rainfall, 6. permeant water, 7. underground water from deep section.

out at the tip of the landslide area weaking the neighbouring soil mass and producing the flowing type slide. The tip of the upper soil mass loses stability and the lower soil mass flows or breaks. As the tip of the upper soil mass moves from loss of stability, the whole upper mass is in a state of possible movement. In normal conditions the landslide soil mass is being constantly undercut by underground water, but not to the degree where the landslide soil mass produces movement and suddend movement cannot be expected. But if an overabundance of water is supplied to the landslide soil mass, the stability of the upper part would be lost due to the intensification of the flowing type slide of the lower soil mass, consequently giving rise to a landslide, or the possibility of a large movement.

Taking into consideration movement mechanism for landslide preventive works, it is thought that there is little stored underground water in the landslide soil mass and that it should be excluded as far as possible before streaming into the landslide area. Accordingly, in order to drain the underground water from the landslide soil mass, several underground drainage bore holes were made by the prefectural authorities toward the distributed areas of the low apparent resistivity values in areas were abundant underground water was suspected or areas of weathered landslide soil mass. From the results, 80 *l*/min. of underground water could be drained from these bore holes. As the holes were made duging the dry season in order to drain as much as possible, it can be expected that they will exhibit a great effectiveness during the rainy season. It was confirmed from these bore holes that the distributed areas of low apparent resistivity values are in the area of the abundant underground water.

5. Conclusion

Selecting the Choja landslide area belonging to the Kurosegawa tectonic zone in the Chichibu terrain and the Wada landslide area belonging to the Mikabu green-rocks zone from among many Fractured zone type landslide areas, the usefullness of the electrical resistivity survey was examined. It was clarified from the results that much usefull data concerning areas could be obtained, ie; electrical resistivity surveys in landslide outline of the slide layer and the surface form of bedrock, condition of the underground water, some idea of the landslide movement mechanism, and the effectiveness of preventive works based on underground water drainage.

Accordingly, in carring out different kinds of landslide investigations in the Fractured zone type landslide area, the electrical resistivity suevey was conducted in all areas first, and information concerning the above questions was obtained. On the basis of this information, landslide investigations and landslide preventive works can be conducted effectively and with less expense.

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